Characteristics of EEG signals during tough and easy linguistic problem solving

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***Abstract*: In the present EEG coherence study, we investigate the brain activation patterns and resource allocation strategies of high-intelligent individuals as compared to low-intelligent individuals while they solve linguistic problems with two levels of complexity. Results of our study supports both efficiency and resource hypothesis. Our findings suggest that high intelligent individuals allocate fewer resources and recruit minimum task relevant brain areas when the task is perceived easy but allocate more resources and recruit several brain areas when the task demand is high. Low intelligent individuals, on the contrary, do not modulate their resource allocation. These results strongly suggest that high intelligent individuals modulate their resource allocation strategies based on the perceived complexity of the task. The study also shows that EEG coherence can be a good indicator to identify intelligence of individuals in a given task.**

Keywords- Intelligence; EEG; Coherence analysis; Neural efficiency; Resource allocation

I. INTRODUCTION

Cognitive activities require consumption of resources that are limited and dependent on neurotransmitter functioning, metabolic system supporting the neural system and the structural connectivity of the neural system [1]. Variation within the availability and allocation mechanism of these resources is considered to be the primary basis for individual differences in intelligence. Thus, finding methods to determine these differences to identify intelligence of an individual is a primary research topic in educational psychology. A greater understanding of individual's potential can help in designing customized instruction material for better learning.

In last few years, several attempts have been made to explain the nature of intelligence. Some studies characterize intelligence in terms of extra ordinary activity in certain parts of the brain such as posterior parietal cortex [2], while some argue that individuals with high intelligence possess extra cognitive resources, which enables them to solve demanding tasks differently [3]. However, some argue that it is not the availability of extra cognitive resources or dedicated neural mechanism but it is the efficient deployment of limited cognitive resources, which characterizes intelligence [4]. But despite the availability of several studies that have tried to understand the brain activation patterns of intelligent individuals in various domains such as music [5], language [6], etc., it still remains a problem to determine the intelligence of an individual. Therefore, the purpose of this study is to investigate how individuals with high-intelligence process information and recruit brain areas while solving linguistic problems with two levels of difficulty: *easy* and *tough*. We assume that the processing patterns in different levels of complexity will help in understanding overall processing and resource allocation patterns of intelligent individuals in general. To determine the brain activation and resource allocation, we used coherence analysis of Electroencephalogram (EEG) signals. Coherence analysis reveals the brain activation patterns and indicates communication between two brain areas where neuronal groups activate together.

The rest of the paper is organized as follows: in the next section, we discuss the background of the study. In section 3, we present our experimental setup and design. In section 4, we report the results of EEG coherence. In section 5, we discuss the outcome of our results and present our conclusions and future plans.

II. BACKGROUND OF THIS STUDY

A. *Neural vs Resource hypothesis*

In regard to resource allocation mechanism of intelligent individuals, several competing hypothesis have been proposed. In particular *efficiency hypothesis* and *resource hypothesis* have got considerable attention in last few years. Several behavioral and brain imaging studies have supported these hypotheses independently. According to *efficiency hypothesis* it is assumed that individuals with high intelligence process information efficiently and establish a large-scale distributed network through selective recruitment of task appropriate specialized neuronal population and suppress task irrelevant and competitive neural networks [7, 8]. In a positron-emission-tomography (PET) study, Haier and colleagues observed negative correlations between intelligence and the extent of energy consumption (glucose metabolism) in the brain during cognitive task performance [3, 8]. However, on the other hand, according to *resource hypothesis* it is assumed that high-intelligent individuals have extra cognitive resources to allocate for a given task as compared to less-intelligent individuals [9].

B. *Coherence analysis and intelligence*

To study the underlying cortical activities, different analysis methods of EEG has been used. Coherence being one of them can be used as an index of functional cortical connectivity in a variety of research contexts [10, 11]. This method gains the information on frequency band related neuronal synchrony between different EEG channels. The coherence analysis is defined as

$$C_{ij}(f) = \frac{S_{ij}(f)}{\sqrt{S_{ii}(f)\, S_{jj}(f)}} \qquad (1)$$

where S_{ij}(f) means the cross spectrum between $x_i(f)$ and $x_j(f)$ which are Fourier transforms of time series signal at the channel i and j. Coherence was calculated between all possible electrode pairs (496) in the following frequency bands: theta band: 4~8[Hz], upper alpha: 10~13[Hz]. In this paper, we report significant coherence in these frequency bands.

A concurrent activation between electrodes of different regions during a cognitive task may be a functional mechanism for efficient task completion [12]. Several studies have supported the view that coherent oscillations in different frequency bands play a crucial role in the dynamic functional integration of brain structures involved in ongoing mental activity [13-15]. And, Coherence or network measure of EEG typically reports correlation between neural complexity and intelligence. For example negative correlations between EEG coherence & IQ especially in the frontal lobes have been reported [16, 17] and increased dimensionality of the EEG is reported as being positively correlated with IQ in the eye closed resting condition [18]. Some more studies show that increased neural efficiency in terms of coherence brain networks is positively correlated with intelligence [19, 20]. Overall suggesting that coherence can be an important measure to understand the brain mechanism of intelligence.

III. Experiment

Aim of our study was to determine the difference and/or similarity in brain activation patterns of high intelligent individuals and low intelligent individuals while they solve linguistic problems using EEG coherence method. In this study, we tested Korean-speaking high school students. They were divided into two groups: high performers and low performers. Their EEG data were recorded when they solved linguistic problems with two levels of complexity: tough and easy. We analyzed the EEG coherence for the task period in relation to subjective rest state.

A. *Participants*

Twenty-Four healthy Korean-speaking students (fourteen females and ten males) from seven different high schools in and around Daegu city, South Korea, participated in the study. Their mean age was sixteen years (SD=1). No participant had significant eye-problems and reported no difficulty reading text on a computer screen much smaller than the text used in our experiment. Data of 7 participants could not be analyzed because of poor quality and noise.

B. *Pre-test to determine the intelligence*

All the participants were given a pre-test before the actual experiment to determine their level of intelligence. For this, all twenty-four participants were given 218 questions from worknet[1]. Based on their response they were given scores. Participants who scored more than 100 were categorized as High-Performers: HPs (individuals with high intelligence) and those who scored less than 100 were categorized as Low-Performers: LPs (individuals with low intelligence). The pretest was conducted in Korean language. And, instructions were also given in Korean language.

C. *Task material*

The task material was taken from the problem set of Seoul Education Centre, SSAT (Samsung Aptitude Test). The instructions and problems were presented in Korean language. The task included problems related to comprehension, word matching and grammar.

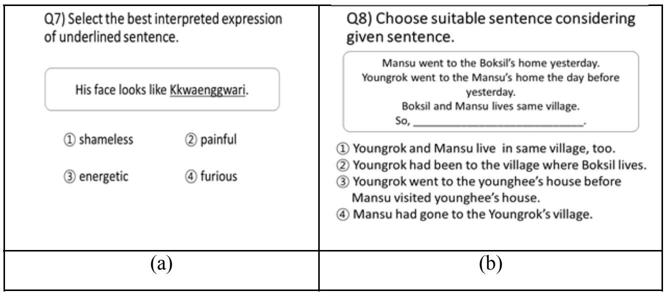

Figure 1. An example of language task material as presented to participants (actual stimuli was shown in Korean)

D. *EEG recording*

EEG was recorded from 32 scalp electrodes (Bio-semi ActiveTwo) placed in accordance with the international 10/20 system with low and high cut filters set at 0.3 and 100 Hz, respectively. Electrode resistance was below 5 kΩ. Signals were recorded from following channels: Fp1, Fp2, AF3, AF4, F3, F4, F7, F8, Fz, FC1, FC2, FC5, FC6, C3, C4, Cz, T7, T8, CP1, CP2, CP5, CP6, P3, P4, P7, P8, Pz, PO3, PO4, O1, O2, Oz). EEG signals were recorded during (1) resting stage (initial 10 seconds) and (2) task stage. EEG data were digitized at a sampling rate of 2048 Hz. Artifact-free epochs of resting EEG per subject were processed and served as 'baseline' for the task condition.

E. *Procedure*

Questions were presented on a 21-inch screen monitor (1280 x 1024). The distance between participants and the screen was around 60-80 [cm]. A total of 10 questions were presented to each participants with a gap of ten seconds between each question (see figure 2). Participants were instructed to solve the given problem and press space bar to go to the next problem else they could press the right arrow key on keyboard if they did not know the answer. Once all questions were answered, EEG cap was removed and participants were made to sit on a different chair. They were given a printed version of same questions and asked to write their answers. They were also instructed to give a rating on a

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scale of 1-7 for perceived difficulty (1 being very easy and 7 being very tough), which served as the basis for determining the perceived complexity of each task.

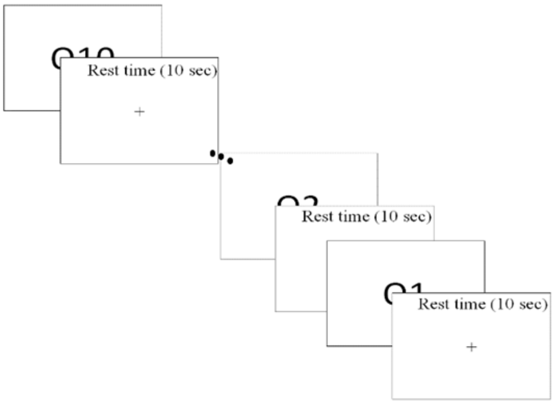
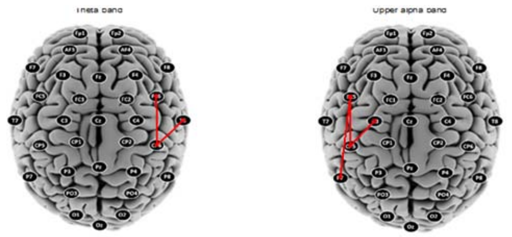


Figure 2. Procedure of the experiment

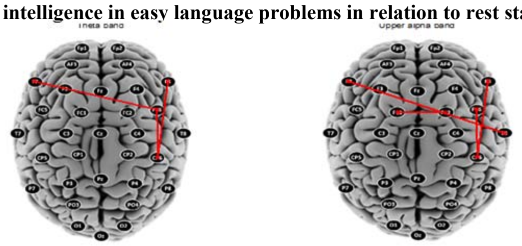
IV. RESULTS

We analyzed EEG coherence of high and low intelligent individuals in theta and upper alpha bands as they have been shown to reflect cognitive processing and resource allocation [21]. Figures 3 and 4 show the coherence (in theta and upper alpha band) of Individuals with high and low intelligence consecutively in easy- linguistic tasks in relation to rest state. For participants with high intelligence, we found coherence within temporal lobes. We did not find any inter-hemispheric cooperation. On the other hand, for low-performers, we found higher inter-hemispheric cooperation between left frontal and right temporal cortex. An increased cooperation between right temporal and left frontal cortices in theta and upper alpha frequency bands was also found.



(a) Theta band (b) Upper alpha band

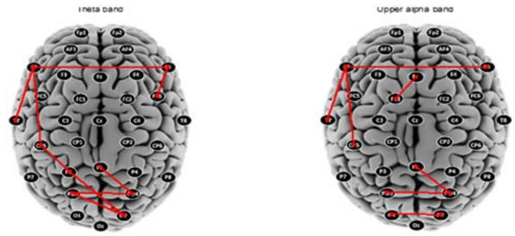
Figure 3. Significant mean coherence (p<0.05) of participants with high intelligence in easy language problems in relation to rest state



(a) Theta band (b) Upper alpha band

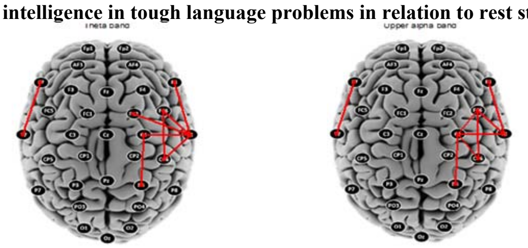
Figure 4. Significant mean coherence (p<0.05) of participants with low intelligence in easy language problems in relation to rest state

In the case of tough-linguistic tasks (figure 5 and 6), we found a significant difference in terms of deployment of resources. For high performers, there was intra-hemispheric as well as inter-hemispheric cooperation. We found bilateral coherence between each frontal corticesexes. However, for low-performers, theta and upper alpha bands showed small distance cortico-cortical cooperation was found suggesting heavy recruitment of various resources. We also found an increase in intra-hemispheric cooperation in both hemispheres. This increase was observed between right parietal and right temporal cortex.



(a) Theta band (b) Upper alpha band

Figure 5. Significant mean coherence (p<0.05) of participants with high intelligence in tough language problems in relation to rest state



(a) Theta band (b) Upper alpha band

Figure 6. Significant mean coherence (p<0.05) of participants with low intelligence in tough language problems in relation to rest state

V. DISUSSION AND CONCLUSION

In this study we explored the differences and/or similarity in significant brain activation patterns and resource allocation strategies between individuals with high-intelligence and low-intelligence while they solved tough and easy linguistic problems. We found that-high intelligent individuals used fewer resources while solving easy tasks but used comparatively more resources for tough tasks in terms of involvement of brain areas. However, low-intelligent individuals used more resources in both easy and tough tasks. This finding indicates that high intelligent individuals are more flexible and modulate their resource allocation pattern depending on complexity of the task. It is possible that tough linguistic tasks required novel and creative connections and easy tasks could be solved using learnt skills from memory. Novel connections require greater resource allocation and involvement of several brain areas including temporal, parieto-occipital and frontal. This suggests; individuals with high intelligence could assess the complexity of the task and allocate resources accordingly. If the task could be solved with already learnt skills, resources were preserved but when the task demand was high, more resources were allocated. Low intelligent individuals, on the contrary, could not assess the complexity of the task and failed to modulate their resource allocation.

In general, our finding supports the assumptions of both neural *efficiency* and *resource* hypothesis of intelligence. High intelligent individuals appear to have a mechanism of recognizing the complexity of the task and then recruit only task demanding and relevant brain areas. We also analyzed the patterns of coherence in the background of available information about cortical specializations. But we do not present them in this paper. On the basis of our analysis we argue that it is not the efficient use or availability of the resource alone which characterizes intelligence. There is more to it. One of them being the ability to assess the complexity and/or the type of task in advance and modulate resource allocation accordingly. In this study, we investigated the influence of complexity. However, it would be interesting to see if the type of task such as mathematics, spatial, etc. too influences the modulation. It is also intriguing to ask how high intelligent individuals can assess the complexity and/or type of the task in advance. We would like to study the pre-stimulus stage of overall processing for a better understanding of resource allocation strategies of high intelligent individuals.

Findings of this study has large implications in terms of identifying potential of children with multiple intelligence in early ages and train them according to their interest and potential. Our findings can be very useful for multiple intelligence research proposed by Gardner [22] and education training methods [23]. Although, we conducted study only on language tasks, this can be replicated on other kinds of tasks such as spatial, music, communication, mathematics, etc. Also, we would like to conduct similar studies to find the effect of gender, age and culture on resource allocation strategies. It would be interesting to see how the capacity to recognize the complexity of task develops with the age or differs with gender and in different cultures.

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